TOTAL LEAST SQUARES FITTING OF ORDERED DATA WITH POLYNOMIAL SPLINES

C.F. Borges, Associate Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To develop fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

SUMMARY: This unfunded effort is a continuing research project. The idea is to fit parametric polynomial spline curves to ordered data to get the best possible fit. Unlike traditional least-squares methods we assume that errors may occur in both the x and y directions. Moreover, we allow the data to be completely general - in particular, it does not have to be functional in nature, it may overlap itself or change directions without restriction. All that is required is an ordered set of points in the plane. I have investigated a variety of different approaches and have developed some very fast and robust algorithms for solving the problem for a single Bezier curve. I have also started work on extending this approach to multi-segment Bezier curves with arbitrary continuity conditions.

DoD KEY TECHNOLOGY AREAS: Other (Scientific Computation)

KEYWORDS: Curve Fitting, Data Compression, Approximation Theory

RESEARCH IN THE STRUCTURAL DYNAMIC RESPONSE OF THE RAH-66 COMANCHE HELICOPTER

D.A. Danielson, Professor
Department of Mathematics
Sponsors: Comanche Program Office and Naval Postgraduate School

OBJECTIVE: For the calendar year 2000, the NPS Comanche Team used Dytran to model the effects of an internal explosion on three different structures. First, a square box was constructed with a centrally located charge to validate and gain early experience with Dytran. Second, a section of the Comanche tail cone (EMD phase) was constructed for future correlation studies to see if this area is survivable. Third, the forward tailcone of the Static Test Article (STA) was modeled to compare with results of recent live fire tests.

PUBLICATION:

Danielson, D. A., "Research in the Structural Dynamic Response of the RAH-66 Comanche Helicopter," Naval Postgraduate School Technical Report, NPS-MA-001-01, December 2000.

THESIS DIRECTED:

Stephan, A. H., "Computerized Ballistic Modeling of the Comanche Tailfan Shroud," Masters Thesis, Naval Postgraduate School, December 2000.

DoD KEY TECHNOLOGY AREAS: Air Vehicles

KEYWORDS: Helicopters, Airframes, Explosions, Computer Software

NUMERICAL TRAJECTORY OPTIMIZATION

F. Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Draper Labs

OBJECTIVE: To solve trajectory optimization problems that arises in astronautics by spectral collocation method.

SUMMARY: The purpose of this study was to investigate different spectral collocation techniques to solve a variety of trajectory optimization problems. Both Legendre and Chebyshev polynomials were used as the basis functions for approximation of the states and control variables of the underlying optimal control problems and highly accurate results were obtained for solutions to problems in orbit maintenance, spacecraft launch and orbit transfer.

PUBLICATIONS:

Fahroo, F. and Ross, I.M., "Costate Estimation by a Legendre Pseudospectral Method, to appear in the *Journal of Guidance, Control and Dynamics,* Vol. 24, No. 2, 2001.

Fahroo, F. and Ross, I.M., "A Spectral Patching Method for Direct Trajectory Optimization," to appear in the *Journal of the Astronautical Sciences,* Vol. 48, No. 2/3, April-September 2000.

Fahroo, F. and Ross, I.M., "A Second Look at Approximating Differential Inclusions," *Journal of Guidance, Control and Dynamics,* Vol. 24, No. 1, 2001.

Fahroo, F. and Ross, I.M., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," accepted in the *Journal of Guidance,* Control and Dynamics, September 2000.

Yan, H., Fahroo, F., and Ross, I.M., "Accuracy and Optimality of Direct Transcription Methods," *Proceedings of the AAS/AIAA Space Flight Meeting,* in Clearwater, FL, January 2000.

Fahroo, F. and Ross, I.M., "A Spectral Patching Method for Direct Trajectory Optimization," The Richard H. Battin Astrodynamics Symposium, College Station, TX, 20-21 March 2000, Paper AAS 00-260.

Fahroo, F. and Ross, I.M., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," *Proceedings of the American Control Conference,* Chicago, IL, June 2000, pp. 3860-3864.

Fahroo, F. and Ross, I.M., "Trajectory Optimization by Indirect Spectral Collocation Methods," Proceedings *of the AIAA/AAS Astrodynamics Specialist Conference*, in Denver, CO, August 2000, pp. 123-129.

Yan, H., Fahroo, F., and Ross, I.M., "Optimal Feedback Control Laws by Pseudospectral Approximations," submitted to the American Control Conference 2001, September 2000.

PRESENTATIONS:

Fahroo, F., "Accuracy and Optimality of Direct Transcription Methods," presented at the AAS/AIAA Space Flight Meeting, in Clearwater, FL, January 2000.

Fahroo, F., "A Spectral Patching Method for Direct Trajectory Optimization," presented at the Richard H. Battin Astrodynamics Symposium, College Station, TX, 20-21 March 2000.

Fahroo, F., "Spectral Collocation Approximations for Optimal Control Problems," presented at the AMS 2000 Sectional Meeting, University of Louisiana at Lafayette, LA, 14-16 April 2000.

Fahroo, F., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," presented at the American Control Conference, Chicago, IL, June 2000.

Fahroo, F., "Direct Trajectory Optimization by a Chebyshev Pseudospectral Method," presented at the American Control Conference, Chicago, IL, June 2000.

Fahroo, F., "Trajectory Optimization by Indirect Spectral Collocation Methods," presented at the AIAA-ASC 2000 Meeting, Denver, CO, August 2000.

THESIS DIRECTED:

Hallbach, L., "A Numerical Study of Fuel-Optimal Low Earth Orbit Maintenance," Masters Thesis, Naval Postgraduate School, December 2000.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Costate Estimation, Optimal Control Theory, Legendre and Chebyshev Pseudo-spectral Method, Low-Earth Orbiting Spacecraft, Minimum Fuel Consumption

FORMATION CONTROL WITH AIR FORCE APPLICATIONS

Wei Kang, Assistant Professor
Department of Mathematics
Sponsor: Air Force Research Laboratory

OBJECTIVE: The objectives of the project are 1.The development of theoretical basis for the formation control of multiple vehicles: 2. Design controllers and STR projections for formations of spacecraft. 3. Coordinated control of orientation and pointing of multi-satellite systems. 4. Carry out simulations and experiments to test the formation control algorithm and the designed controllers.

SUMMARY: The PI visited AFRL on WPAFB for two weeks to collaborate with the AFRL research team in this subject. The design algorithm based on perceptive frame developed in NPS and MSU is combined with the sliding mode controller developed in AFRL. A joint paper with AFRL on satellite formation control is submitted to AIAA conference based on the collaboration.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: STR Projections, Formation Control Algorithm

VISIBLE SETS AND ITS MANUFACTURING APPLICATIONS

Wei Kang, Assistant Professor
Department of Mathematics
Sponsors: Ford Scientific Research Laboratory

OBJECTIVE: The focus of this project for the year of 2000 is on the production planning based on information feedback. The objective is to develop mathematical model for production planning taking the advantage of today's high-speed internet data transfer. The purpose of developing such model is to provide theoretical tools for analysis and automation for future B-to-B e-commerce in automotive and similar industries.

SUMMARY: Mathematical model of production planning integrating both statistical data and IT based fast information feedback is developed. A cost function is developed for dynamical production planning and adaptive optimization. Max-Plus algebra is used to model flexible production lines. The paper based on

this project won the "Best Paper Award" in the 6th International Conference on Control, Automation, Robotics and Vision held in Singapore in December 2000. The award is selected among about 360 papers published in the conference.

DoD KEY TECNOLOGY AREAS: Other (Mathematical Modeling)

KEYWORDS: Production Planning, B-to-B e-Commerce

COORDINATED FORMATION AND ATTITUDE CONTROL OF MULTI-SATELLITE SYSTEMS

Wei Kang, Assistant Professor
Department of Mathematics
Sponsors: Air Force Research Laboratory

OBJECTIVE: The objective of this project is to design a cooperative controller for the coordination of multiple satellites flying in formation. It includes the development of feedback for individual satellite, the coordination of multiple feedbacks, and coordination strategies for the relative attitude control of multiple satellites**.**

SUMMARY: Both sliding mode controller and H-infinity controller are developed for the attitude control of individual satellites. The proposed cooperative control is based on the perceptive frame. Some simulations show a significantly reduced overall tracking error. A conference paper and a journal paper are submitted as part of the product from this project.

DoD KEY TECHNOLOGY AREAS: Space Vehicles

KEYWORDS: Attitude Control, Multiple Satellites

ENHANCED EM RADIATION SOURCE IMAGING

M. A. Morgan, Professor
Department of Mathematics
Sponsor: Office of Naval Research

OJBECTIVE: Multi-solution expansions will be combined with singular value decomposition to investigate optimized inverse scattering. Near-field data will be measured at the NRL test facility and used to experimentally validate the procedures developed here.

DoD KEY TECHNOLOGY AREAS: Sensors

KEYWORDS: Signatures, Spectral Decomposition

MAGNETIC FIELD SENSOR PLACEMENT

M. A. Morgan, Professor
Department of Mathematics
Sponsor: Office of Naval Research

OBJECTIVE: The major technical objective of this research is to investigate robust techniques for predicting spatial B-field signatures of elongated magnetic objects using vector field measurements near to the object. Of significant importance is development of a procedure for predicting the number and optimal

placement of the field sensors to attain a desired accuracy level in the presence of noise and other measurement errors.

SUMMARY: Fiscal Year 2000 progress involved: (1) development of the field generation program for the dipole enclosed in a hollow prolate spheroidal shell, and (2) initial evaluation of the least-squares field prediction algorithm for single mode test fields. Work during this first year's effort has involved only the m=0 axisymmetric field mode set.

PRESENTATIONS:

Morgan, M.A., "Near-Field Imaging Using Cylindrical Harmonic Back-Propagation," PIERS 2000, Cambridge, MA, 10 July 2000.

Morgan, M.A., "Null Spaces in Equivalent Current Field Generation," PIERS 2000, Cambridge, MA, 10 July 2000.

THESIS DIRECTED:

Yopp, Stacey, "Magnetic Field Sensor Placement," Masters Thesis, Naval Postgraduate School, June 2001.

DoD KEY TECHNOLOGY AREAS: Sensors, Modeling and Simulation

KEYWORDS: Near-Fields, Magnetic Field Imaging

IMPULSE ANTENNA MODELING

M. A. Morgan, Professor
Department of Mathematics
Sponsor: Naval Surface Warfare Center

OBJECTIVE: The goal of this task is to investigate the impulse radiation characteristics of specified antennas in the presence of buildings over real earth.

SUMMARY: Wire-grid numerical modeling of antenna and building structures has been completed using frequency-stepped calculations using GNEC. Impulsive near-fields within the modeled building is found using time-domain source modeling and inverse FFT convolution. Animations of fields within the structure are created using custom MatLab programs.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Impulse Response, Antenna Modeling, Near-Fields, GNEC

WIDEBAND LOW-PROFILE COMMUNICATION ANTENNA DESIGN

M.A. Morgan, Professor
Department of Mathematics
Sponsor: Army Research Office

OBJECTIVE: A finite element algorithm was developed for use in designing omnidirectional wideband VHF communication antennas having low-drag blister type profiles for use on helicopters.

SUMMARY: An analysis tool has been created for use in the design of efficient wideband VHF omnidirectional antennas for employment on Army helicopters. Dielectric loading can be used to optimize impedance matching and antenna pattern over a desired range of frequency. Tapered feed and flare

sections, without dielectric loading, provide impedance matching over ultra-wide bandwidths. The finite-element solution uses the coupled-azimuthal potential field formulation with mesh termination by the field-feedback technique. This software tool allows designers to optimize performance while constraining the antenna's physical profile through use of inhomogeneous lossy dielectric loading.

DoD KEY TECHNOLOGY AREAS: Sensors, Modeling and Simulation

KEYWORDS: Wideband, Finite Elements, Antenna Design

ATTITUDE DETERMINATION

B. Neta, Professor
Department of Mathematics
Sponsor: Unfunded

SUMMARY: Various k-vector range searching techniques are presented. These methods accomplish the range search by taking advantage of an n-long vector of integers, called the k-vector, to minimize the search time. The price is increased memory requirement for the k-vector allocation. However, it is possible to balance the extra memory required and the speed attained by choosing a step parameter h, which samples the k-vector. A two-level k-vector technique is also presented to minimize the speed of the admissible data identification associated with a given range. The proposed methods are compared with the well-known "binary search" technique, and demonstrate a high-speed gain rate (from 9 to more than 40 times). Finally, just to show one of the wide-range possible applications, a method to compute the *arcsin* function, based on the k-vector technique and a look-up table, is presented.

PUBLICATIONS:

Kluever, C.A., Neta, B., Hall, C.D., and Hanson, J.M., "Advances in the Astronautical Sciences," *Spaceflight Mechanics 2000*, Vol. 105, Univelt, Inc., San Diego, CA, 2000 (two-volume book).

Mortari, D. and Neta, B., "k-Vector Range Searching Techniques," *Proceedings AAS/AIAA Space Flight Mechanics Meeting*, Clearwater, FL, 23-26 January 2000, Paper Number AAS 00-128.

PRESENTATION:

Neta, B., "k-Vector Range Searching Techniques," AAS/AIAA Space Flight Mechanics Meeting, Clearwater, FL, 23-26 January 2000.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Attitude Determination, Search Algorithms

GPS TRAJECTORY AVERAGING

B. Neta, Professor
Richard Franke, Professor
Department of Mathematics
Sponsor: National Imagery and Mapping Agency

SUMMARY: Numerous independent sets of data have been taken or obtained. The steps in carrying out the required tasks are: partition sets of data into pieces that correspond to a particular part of a roadway and that have been taken using a single satellite configuration, select a portion of that path to be fit by a straight line or by a parametric cubic curve with continuous tangent vector, and compare the curves

obtained for independent sets of data over the same path to estimate the bias vector between the two. When these steps are performed for many independent tracks an estimate of the true bias can be obtained. Matlab programs have been written that perform each of the above tasks.

PUBLICATION:

Clynch, J.R., Franke, R., and Neta, B., "Improvements in Dynamic GPS Positions Using Track Averaging," *Proceedings of the ION Technical Meeting*, Anaheim, CA, 26-28 January 2000.

PRESENTATION:

Neta, B., "Improvements in Dynamic GPS Positions Using Track Averaging," ION Technical Meeting, Anaheim, CA, 26-28 January 2000.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: GPS, Bezier, Matlab

EFFICIENT NONLINEAR TRANSIENT DYNAMIC ANALYSIS FOR STRUCTURAL OPTIMIZATION USING AN EXACT INTEGRAL EQUATION FORMULATION

B. Neta, Professor
Department of Mathematics
J.H. Gordis, Associate Professor
Department of Mechanical Engineering
Sponsor: National Science Foundation

SUMMARY: The focus of this phase of the project is the development of an improved solution algorithm for fast transient analysis of large, locally nonlinear structures using time domain structural synthesis. Time domain structural synthesis is a general and exact formulation for transient problems in structural modification, substructure coupling, and base excitation. The formulation is characterized by the governing equation of the synthesis, which is a nonlinear Volterra integral equation. The governing equation makes use of impulse response functions calculated for those coordinates of the sub-structures subjected to forces of synthesis (e.g. modification forces, coupling forces). This physical coordinate formulation provides for a largely unrestricted and exact model reduction, in that only those coordinates of interest need be retained in the synthesis. We document the development of several algorithms intended to improve upon the original algorithm developed by Gordis. The last algorithm developed meets the stated goals of the project. This algorithm is a newly developed recursive, block-by-block convolution solution to the governing nonlinear integral equation. As is demonstrated with a simple but realistically large nonlinear base excitation problem (51,500 DOF finite element model), the new algorithm provides a 78% reduction in time required for the nonlinear transient base excitation solution, as compared with traditional direct integration calculated using a widely-used commercial finite element program. This very large savings in computer time is obtained for a single analysis, i.e. assuming no prior calculations have been made for the impulse response functions of the sub-structures. The new algorithm provides an even greater reduction in computer time for all subsequent analyses. As shown in the example problem, once all required impulse response functions have been calculated, the nonlinear base isolation solutions calculated using the new recursive, block-by-block convolution algorithm take approximately seven seconds, as compared with the direct integration solution, which takes approximately 30 minutes. This rapid reanalysis capability will facilitate the development of numerical optimization for the design of nonlinear isolation.

PUBLICATIONS:

Gordis, J. and Neta, B., "An Adaptive Method for the Numerical Solution of Volterra Integral Equations," *Recent Advances in Applied and Theoretical Mathematics*, N. Mastorakis, ed., World Scientific and Engineering Society International Conference, Athens, Greece, 1-3 December 2000, pp. 1-8.

Gordis, J. and Neta, B., "Fast Transient Analysis for Locally Nonlinear Structures by Recursive Block Convolution," *ASME Journal of Vibrations and Acoustics*, submitted for publication.

PRESENTATION:

Neta, B., "An Adaptive Method for the Numerical Solution of Volterra Integral Equations," World Scientific and Engineering Society International Conference, Athens, Greece, 1-3 December 2000.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Finite Elements, Structural Synthesis, Convolution, Block-by-Block, Adaptive

ORBIT DETERMINATION

B. Neta, Professor
Department of Mathematics
Sponsor: Unfunded

SUMMARY: Super implicit and Obrechkoff high order methods were compared for the solution of first and second order initial value problem. The second order problems of interest are those not containing first derivatives.

PUBLICATIONS:

Neta, B. and Fukushima, T., "Obrechkoff Versus Super-Implicit Methods for the Solution of First and Second Order Initial Value Problems," *Computers and Mathematics with Applications*, special issue on Numerical Methods in Physics, Chemistry and Engineering, T. E. Simos and G. Abdelas, eds., (accepted for publication).

Neta, B. and Fukushima, T., "Obrechkoff Versus Super-Implicit Methods for the Integration of Keplerian Orbits," *Proceedings of the AIAA/AAS Astrodynamics Specialist Conference*, Denver, CO, 14-17 August 2000, Paper Number AIAA 2000-4029.

PRESENTATION:

Neta, B., "Obrechkoff Versus Super-Implicit Methods for the Integration of Keplerian Orbits," AIAA/AAS Astrodynamics Specialist Conference, Denver, CO, 14-17 August 2000.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Orbit Determination, Initial Value Problems